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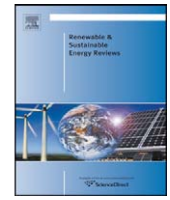

Net energy balance of molasses based ethanol: The case of Nepal

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ABSTRACT

This paper evaluates life cycle energy analysis of molasses based ethanol (MOE) in Nepal. Net energy value (NEV), net renewable energy value (NREV) and energy yield ratio are used to evaluate the energy balance of MOE in Nepal. Total energy requirements in sugarcane farming, cane milling and ethanol conversion processes are estimated and energy allocation is made between co-products (molasses and sugar) as per their market prices. The result shows negative NEV (−13.05 MJ/L), positive NREV (18.36 MJ/L) and energy yield ratio (7.47). The higher positive value of NREV and energy yield ratio reveal that a low amount of fossil fuels are required to produce 1 L of MOE. However, negative NEV reveals that the total energy consumption (both fossil and renewables) to produce the ethanol is higher than its final energy content. Nevertheless, the renewable energy contribution amounts to 91.7% of total energy requirements. The effect of the increased price of molasses and reduced energy consumption in the sugarcane milling and ethanol conversion are found to be significant in determining the energy values and yield ratio of MOE. In addition, there are clear measures that can be taken to improve efficiency along the production chain. Finally, energy security, scarcity of hard currency for importing fossil fuels and opportunities for regional development are also strong reasons for considering local renewable energy options in developing countries.

Contents

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1. Introduction

Nepal is a poor economy with only US$ 350 GDP per capita [1]. The country faces tremendous problems to secure the supply of petroleum products necessary to meet the national demand for the transport, residential and industrial sectors. NOC (Nepal Oil Corporation) is the state owned venture responsible for oil imports and the only supplier of oil products in the market. According to NOC, 752,446 m^3 of petroleum products (diesel: 39.8% and gasoline: 13.1%) were imported from India in 2006/2007, mainly to meet transport needs. The number of vehicles in the country is increasing at an average rate of 13.5% per year since 1990/1991, and more than 56% of the vehicles are registered in the Kathmandu Valley, the capital city of Nepal [2].

Energy security for transport is a quite severe problem in Nepal. The country faces frequent shortage of transport fuels, and public protests against fuel price rises are common. NOC faces serious financial problems due to mounting debts in oil import bills. NOC is selling the petroleum products for less than it pays the Indian Oil Corporation for it, and has not always been able to meet the demand of imported fuels in the country. Though NOC rose prices of major petroleum products at rates of 9–27% in June 2008, the company was accumulating losses at the order of 1.7 billion Nepalese rupees per month [3]. Instability in oil prices and deliveries has put a large burden on the Nepalese economy, compromising the country's development.

In an effort to reduce dependence on imported fuels and enhance domestic energy security, the government of Nepal (GoN) has decided to blend 10% ethanol in the petrol. The decision was motivated by high oil prices, together with the acknowledgement of the country's capacity to produce ethanol. Nevertheless, the measure has not been implemented due to technical and economic problems. In fact, there is no ethanol blend available in the market for the transport sector in Nepal yet. Meanwhile, the government has formed a high level committee early 2008 to find ways 'to reduce the consumption of petroleum products by increasing the use of alternative energy' [4].

Nine sugar mills are operating in Nepal with total installed capacity of 17,050 tonnes of cane processing per day. Sugar mills are well established and contributing to the national economy, and they have an enormous potential to produce ethanol from their by-product, molasses. Among the sugar mills, Sri Ram Sugar Mills Ltd. (SRSM) has installed a 30 m^3/day molasses based ethanol (MOE) plant to produce ethanol for transport, but the plant is not operational.

The use of bioethanol as transport fuel is growing fast following on Brazilian positive experiences and, more recently, US policies. Ethanol sources may vary from country to country. In the US, corn is being used. Developing countries like Thailand and India are producing ethanol using the sugar industries' by-product, so-called molasses based ethanol. This contrasts with the Brazilian ethanol that is usually produced in parallel with sugar or in specialized ethanol plants. In any case, ethanol has recently been subject to a lot of scrutiny mainly in the fuel versus food debate [5]. The energy balance of ethanol has also been questioned. For that matter, a number of studies have been done in various countries to verify the energy balance of the ethanol being produced and the real potential for climate change mitigation. In this study, we assess the contribution of Nepalese molasses based ethanol verifying the net energy value/balance (NEV or NEB) of the ethanol nationally produced.

NEV evaluates net energy (surplus or deficit) after deducting energy inputs in the production phase from the energy content of the derived product, in this case ethanol. It measures whether the alternative fuel option is attractive from an energetic point of view. Roughly speaking, a positive net energy value provides motivation to opt for the new fuels while a negative value does not. A number of analyses on life cycle assessment (LCA) of the net energy balance for various crops/feedstocks derived bioethanol have been studied. For example, Nguyen et al. performed the full chain energy analysis of fuel ethanol from cassava and cane molasses in Thailand [6,7]. Dai et al. estimated energy efficiency in NEV and net renewable energy value (NREV) of cassava ethanol in China [8]. Shapouri et al. reported the output/input energy ratio (energy yield) of corn ethanol in the US [9]. Rosenschein et al. evaluated energy analysis of ethanol production from sugarcane in Zimbabwe [10]. Macedo et al. calculated the net energy for sugarcane ethanol in Brazil [11]. Prakash et al. examined the energy yield for molasses based ethanol in the case of India, considering the molasses to ethanol production phase only [12].

This study deals with the net energy input/output analysis of molasses based ethanol production in the life cycle perspective in the case of Nepal. It is the first study of its kind in the Nepalese context. The goal is to estimate the net energy value of ethanol from sugar mill's by-product molasses by assessing life cycle energy/material inputs. The study is based on field study information from a sugar industry, Sri Ram Sugar Mills Ltd., in Nepal and its neighbouring sugarcane farms. The study provides useful information to policy makers, investors and individuals to judge the worthiness of policies for alternative transport fuel in Nepal as the country seeks fuel options to meet energy demand and security, and promote sustainable development.

2. Methodology

2.1. Scope of the study and system boundary

The study considers the entire life cycle energy inputs inventory (both fossil and renewables) from sugar cane farming (human labour, irrigation, and chemicals), transportation, sugar cane milling, fermentation and distillation and, finally, dehydration to produce anhydrous ethanol (EtOH, 99.5% (v/v) ethanol) (see Fig. 1). Sugarcane crops absorb solar energy but it is widely available and a common good, so solar energy inputs are not considered in the analysis. The data used have been collected in the field or correspond to energy values derived for Nepal's local conditions according to international practices.

There are two main by-products in the sugar milling process: molasses and bagasse. Bagasse is used as the fuel input to boilers. Bagasse fired boiler's steam is used in power turbines to generate electricity, and the exhaust steam is utilized in the process heating required for sugarcane milling, distillation and dehydration. Molasses are converted into anhydrous ethanol fuel (EtOH) from the route of hydrous ethanol (95% (v/v) ethanol, called rectified spirit). Fermentation and subsequent repeated distillation processes of molasses generate rectified spirit. Distillery waste water effluent (spent wash) is to be treated prior to disposal since treatment is essential from the environmental point of view. Anaerobic effluent treatment plant generates biogas, which is later used as a fuel input to the boilers. Bagasse, which is used to generate steam for the electricity and the process heat, is considered as a renewable energy input into the system. Sugarcane trash, which also has significant energy content, is not considered in the analysis as open burning before harvesting is a common practice in Nepal. Energy incurred to produce machineries/equipment, industrial installations and oil/lubrication in the factory is also not taken into account in this study.

2.2. Definition of NEV, NREV and energy yield ratio

The NEV of anhydrous ethanol (EtOH) is the difference between the energy content of the ethanol produced and the total primary

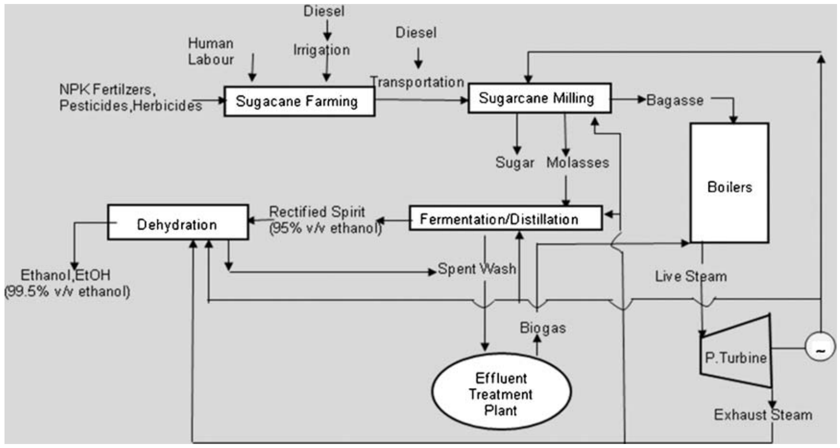

Fig. 1. System boundary of the Nepalese study.

energy inputs (fossil plus renewables) in the entire fuel production cycle.

$$\mathrm{NEV} = E_\mathrm{F} - E_\mathrm{I}$$

where E_F is the energy content (lower heating value) of ethanol, E_I is the amount of total primary energy inputs

Whereas, net renewable energy balance (NREV) is calculated as follows:

$$\mathrm{NREV} = E_\mathrm{F} - NE_\mathrm{I}$$

where NE_I is the non-renewable energy or fossil fuel input.

The energy yield ratio is defined as the ratio of energy content in the ethanol and total fossil energy required to produce it.

$$\text{energy yield ratio} = \frac{\text{energy content in ethanol}}{\text{fossil energy input}}$$

NREV and the energy yield ratio provide essential information to assess the biofuel's contribution to energy security, while NEV gives total input/out energy analysis including renewables. Notice that this study also incorporates energy recovered from the by-products within the system, that is, excess bagasse and biogas, in NEV, NREV and energy yield ratio.

2.3. Material and energy inputs

2.3.1. Sugarcane farming practices

Sugarcane is a cash crop which production has a role in employment and income generation in rural areas. Nepal produced 2.59 million tonnes of sugarcane in 2006/2007 using approximately 64 thousand hectares, thus yielding 40.61 tonnes/ha [13]. For the purpose of comparison, it can be mentioned that average yields are more than double in Brazil. Sugarcane is a multiyear crop and one plantation is harvested 4–5 times. The total duration for sugarcane crop growth is 11–12 months and harvesting time lasts up to 150 crop days, i.e. around five months.

A field study was made in the Sri Ram Sugar Mills Ltd., Rautahat for primary data collection. The SRSM has an intensive dedicated research unit for cane production, and has published a 'how to farm sugarcane' brochure written in Nepalese language for sugarcane farmers. It covers agriculture methods, cultivation seasons, and recommendations on the application of fertilizers, herbicides and pesticides. Interviews with farmers indicate that the actual amount of chemicals used did not meet the recommended value due to availability and price factors (see Table 1). 50% of the recommended qualities were used in the case of the fertilizers (DAP and potash), herbicides and insecticides.

Land preparation, seed plantation, fertilizer/chemicals application, irrigation and harvesting are the main farm activities in terms of energy requirements. Nepal's sugarcane farming practices are characterized by low mechanization, which translates into little or no use of farm machinery and equipment, except for irrigation (water pumps), and only partial harvest transport in trucks and tractors. Human labour is an important input in the sugarcane farming. Labour requirement in the sugarcane farming accounts for about 204 person days per hectare, where one person day is equal to 8 man-hours.

After harvesting, sugarcane is transported to the sugar mill by three modes of transport: animal powered cart, tractor and truck (Fig. 2). Animal-driven carts respond for a large share (around 50%) of this transport. The average distance covered, carrying capacity and mileage (km/L) by these three modes of transport are given in Table 2. For example, a truck carries 10–15 tonnes of cane, and covers 3.5 km/L diesel to carry cane an average of 50 km distance. It is estimated that diesel consumption is 40 L (average value) to transport 40.61 tonnes sugarcane (by both tractors and trucks) produced in 1 ha.

Irrigation plays a key role in increasing the yield of sugarcane. Irrigation is practiced in the summer before monsoon. Nepal Agriculture Research Council (NARC) mentions that light irrigation is required at 7–10 days intervals during the summer season [14]. Irrigation is done approximately 20 times in one season. Water pumps (5–7 HP) are used for irrigation. This machine consumes 15 L of diesel to irrigate 1 ha each time. Hence, the total amount of diesel used for irrigation in one season is 295 L/ha.

Table 3 summarizes the values for fertilizers, insecticides/pesticides, herbicides, diesel used for irrigation and transport, and human labour inputs for cultivation and transport of cane to the gate of the sugar mill as per observed during field study at SRSM.

Table 1
Chemicals/fertilizers use in sugarcane farms per hectare in Nepal.

Type	Recommended by SRSM (kg/ha)	Actual use (kg/ha) (% of recommended quantity)
DAP[a]	221.5	110.75 (50%)
Potash	110.8	55.4 (50%)
Urea	265.9	265.9 (100%)
Herbicides	3.3	1.65 (50%)
Insecticides	26.6	13.3 (50%)

Source: SRSM catalogue and personal interviews with 20 farmers during field study.
[a] DAP is abbreviation for di-ammonium phosphate, which is a chemical fertilizer. It contains 46% phosphate and 16% of nitrogen, thus NPK value for DAP is 16:46:0.

Fig. 2. Different modes of transport system after sugarcane harvesting.

2.3.2. Sugar milling and cogeneration

When the sugarcane arrives at the sugar mill, it is crushed to extract the juice. The water content of the juice is removed in the subsequent heating and evaporation process, leaving a thick concentrated juice (syrup). This syrup is boiled in different pan boilers to stimulate and initiate the sugar crystallization process. A centrifugation process separates solid sugar from the hot concentrated syrup. Boiling, cooling and centrifugation processes are repeated several times in order to recover as much sugar as possible.

Table 2
Modes of the sugarcane transport system in details.

Modes	Capacity (tonne-cane)	Coverage (%)	Mileage (km/L diesel)	Average distance covered (one way)
LP truck	10–15	20	3.5	50 km (max 80 km)
Tractor	7–10	30	4.0	30 km (max 40 km)
Bull cart (animal-powered)	1.5–2.5	50	–	10 km (max 20 km)

Table 3
Materials and human labour inputs in 1 ha sugarcane farm.

Particulars	Units	Quantity	Conversion per kg or litre
Sugarcane yield	tonne/ha^{-1}	40.61	
Fertilizers[a]			
Phosphorous (P_2O_5)	kg/ha^{-1}	50.95	7.5 MJ
Potash (K_2O)	kg/ha^{-1}	55.4	7.0 MJ
Nitrogen	kg/ha^{-1}	140.03	56.3 MJ
Insecticides/pesticides[a]	kg/ha^{-1}	13.3	358 MJ
Herbicides[a]	kg/ha^{-1}	1.65	355.6 MJ
Diesel (irrigation)[b]	L/ha^{-1}	295	38.665 MJ
Diesel (transportation)[b]	L/ha^{-1}	40	38.665 MJ
Human labour[c]	Labour/day/ha^{-1}	204	80.14 MJ

Source: authors' estimation based on field data.
[a] Adapted from Macedo et al. [11].
[b] EIA [27].
[c] Human labour: The energy equivalent of human labour is estimated based on the 'Life-style Support Energy', as adopted by Nguyen et al. in [6,7,28], which states that human labour's energy input can be calculated by multiplying the labour's cost by energy intensity of the economy as follows: energy value of agriculture labour $(\mathrm{MJ/day}) = \mathrm{wage}\,(\mathrm{NRs/day}) \times \frac{\text{per capita primary energy consumption(MJ)}}{\text{per capita GNP(in NRs)}}$. Minimum wage of the Nepali labours is NRs 3300 ($47, with conversion factor 1$ = 70 NRs) per month [29], per capita primary energy supply is 14.28 GJ [30] and GNP is $280 [31]. Here the energy value of agriculture labour is estimated to be 80.14 MJ/day, thus primary energy consumption per hour is 10.01 MJ/h (one labour-day is equivalent to 8 man-hours). Nepal's per capita primary energy consumption pattern is mainly dominated by the use of traditional biomass with the share of 87.71%. Fossil fuels contribute 9.94% (petroleum 8.19% and coal 1.76%) while hydropower and renewables only carry 1.82% and 0.53% respectively, WECS (2006) [32]. The energy input of the human labours is further divided into fossil and renewable as per above WECS's data – 9.94% fossil and 90.06% renewable [30]. For example, a human labour consumes 9.02 MJ and 0.99 MJ renewable and fossil fuels respectively in 1 man-hour.

Bagasse is the fibrous residue left after extraction of the sugar, and it is the feedstock for boilers to generate steam. Molasses are the by-product of the crystallization centrifugation process, at a point when extraction of sugar is no longer possible. Daily production and performance reports from Sri Ram Sugar Mills Ltd. show that 1857 tonnes (average for 76 crop days) and 1797 tonnes (average for 147 crop days) were processed in one day in 2007/2008 and 2006/2007 respectively. In 2007/2008, 1 tonne sugarcane would generate 35% bagasse, 9% sugar and 4.6% molasses. The figures for 2006/07 were 37% bagasse, 7% sugar and 4% molasses.

SRSM has employed around 200 full time staff and 350 temporary staff for seasonal harvesting work (4–5 months). Human labour's input in harvesting has been included in the previous analysis, but human labour energy contribution in the factory operation is not considered in the calculations made in this study.

The sugar milling process is energy intensive. However, since SRSM can meet its own energy requirements, no electricity is bought from the national grid. Catalogues containing specifications of boilers and turbines used in the plant and local inspection were used to find out the details of the electricity consumption at all stages of the milling process. Total electrical power consumption in sugarcane milling process and ancillaries/facilities is estimated at 2416.5 kW (milling 1882.5 kW and ancillaries/facilities 534 kW). Table 4 summarizes the electric power requirements of the plant at various stages in the process.

SRSM has four boilers (total installed capacity 85 tonnes/h) and four back pressure steam turbines (total installed capacity 5.7 MW). Fig. 3 depicts the steam utilization in steam turbine and process heating. The boilers supply steam to the power turbines. Exhaust steam is used for process heating in milling and distillation/dehydration process. Power turbines generate electricity. 3 MW (electricity) is enough to supply electricity input to run pumps, motors and other electro-mechanical equipment, including electricity to the industrial complex. The rest of the turbines remain in stand-by position. Further, out of four boilers, three boilers (installed capacity 65 tonnes/h) are sufficient to meet the demand of electricity required for all processes and ancillaries/facilities in the factory. Boilers generate live steam at 21 kg/cm^2

Table 4
Electric power consumption in the factory.

Items	Power required (kW)
Sugarcane milling process	1882.5
Ancillaries/facilities of sugarcane milling	534.0
Fermentation/distillation	180.0
Dehydration	190.5
Effluent treatment process (ETP)	80.0
Lighting and facilities of distillation/dehydration/ETP	133.0
Total power required in kW	3000.0

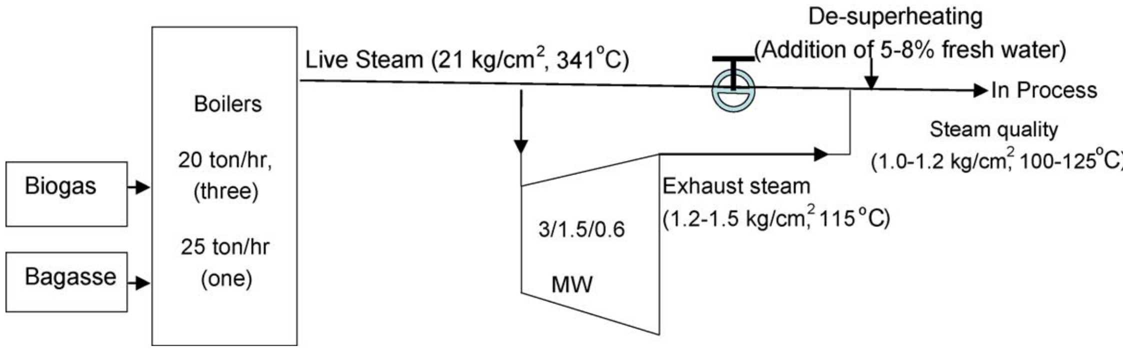

Fig. 3. Steam utilization in power turbine and process heating.

and 340 °C. Energy content of 21 kg/cm^2, 340 °C steam is 3115.76 kJ/kg. Assuming bagasse has 50% moisture and 1.5% ash content and 2% brix content (mass ratio of dissolved sugar to water in a liquid), higher and lower heating value come out to be 9544.2 kJ/kg and 7670.7 kJ/kg respectively [15].

It is found that 1 kg of bagasse generates 2.2 kg of steam and hence 1 kg of steam requires 4.32 MJ of thermal primary energy. Bagasse and steam relation in India and Thailand cases are similar [16,17]. Power turbine exhaust steam at 1.2–1.5 kg/cm^2 is used as the process heat in the sugar milling process. Calculation shows that the overall efficiency of combined heat and power is 66.7%, including electrical efficiency (4.5%) and thermal efficiency (62.3%). The heat and power ratio is 14.

Further, field data and calculation show:

- 56 tonnes/h (=15.56 kg/s) live steam is required to run 3000 kW steam turbine.
- ⇔ 56 tonnes of steam (25.2 tonnes bagasse) is required to generate 3000 kWh of electricity
- ⇔ 1 kWh of power generation requires 18.66 kg of steam (8.4 kg of bagasse)

The manufacturers information on the steam turbines show that approximate steam consumption is 12.6 kg/kWh power generation at 3000 kW, i.e. full load when steam parameters are maintained at design conditions [18]. Thus steam consumption at SRSM is 48% higher than turbine specifications. Obviously, the efficiency of power generation is quite low since the plant is using low pressure and low temperature turbine to generate electricity. In the context of an Indian case study, Purohit et al. mentions that, if high pressure and temperature turbine is used then only 1.6–1.85 kg of bagasse are required to generate 1 kWh [17], thus leading to a huge difference in terms of resource and energy efficiency.

It is assumed that the system losses (33.28%) are equally shared by heat and power. Thus primary energy contribution for power generation and process heat are 1229.4 GJ/day and 4600 GJ/day respectively. The milling process and its ancillaries/facilities use 2416.45 kW (the rest power is for other processes including distillation). This gives a total of 990.3 GJ primary energy consumption per day. The 4600 GJ primary energy are totally used in the sugar milling process as process heat.

Power (electricity) and process heat (steam) consumption in the factory is considered to be the same in full load or partial load (under-capacity) condition, since there is no provision to optimize the electricity and steam utilization. Since Nepal Electricity Authority (NEA), a state owned venture for the national electricity transmission and distribution, does not have any provision to buy electricity from cogeneration plants, the surplus electricity, if available, is simply wasted.

2.3.3. Allocation of molasses for ethanol production

In the LCA methodology, allocations are proportionally made to share the accountability for life cycle resource consumption, emissions and waste streams from processes, when two or more co-products with beneficial value are being produced [19]. Economic allocation is used to divide the resource consumption, here the primary energy, between co-products, molasses and sugar. Primarily, it is a partition of primary energy loads between sugar and molasses coming out from the same system based on their economic values. Guinee et al., and Kim and Dale elaborate the procedure of economic allocation in LCA [20,21].

Nguyen et al. has made the economic allocation for energy partition between sugar and molasses in a Thailand's case [28]. Due to increasing price of molasses in Thailand, the sugar to molasses ratio has dropped from 15 to 8.6 between 2005 and 2006. Yield and price of sugar and molasses are given in Table 5 for the case of Nepal in two consecutive seasons. In 2006/2007 the economic allocation ratio was 22.6 while the value is 21.8 in 2008, getting an average allocation ratio of 22.2:1 (sugar:molasses), which is used to divide the energy inputs in this study. For example, out of 990 GJ primary energy consumption for electricity use in the sugarcane milling process (including its facilities), sugar and molasses take 947.3 GJ and 42.7 GJ respectively.

2.3.4. Fermentation and distillation process

SRSM has its own distillery unit connected to the sugar mill. It produces 95% (v/v) rectified spirit (also called, hydrous ethanol). Fermentation and subsequent distillation process occur in the distillery unit. Molasses from the sugar mills contain 42% (w/w) fermentable sugar. This sugar rich solution is fermented with the help of yeast anaerobes. During the process of fermentation, a basic reaction takes place as follows [12]:

$$C_6H_{12}O_6 + \text{yeast} = 2C_2H_5OH + 2CO_2$$

Table 5
Economic allocation of sugar and molasses – the Nepal's case.

	2006/2007		2007/2008	
	Yield[a] (kg/tonne cane)	Price[b] (NRs/tonne)	Yield[c] (kg/tonne cane)	Price[d] (NRs/tonne)
Sugar	73.6	26,000	88.8	28,000
Molasses	42.3	2,000	45.7	2,500
Allocation ratio (sugar:molasses)	22.6	22.6	21.8	21.8

Source: Authors' calculation based on field information.
[a] Average yield on crop day 147 is taken (last year – 2006/2007).
[b] Average yield on crop day 76 is taken (this year – 2007/2008).
[c] Gate prices of sugar and molasses are NRs 26/kg and NRs 2/kg (2006/2007), and NRs 28/kg and NRs 2.5/kg (2007/2008) respectively.

Table 6
Details of the distillery plant.

Parameters	Values
Process inlet molasses quality	42% (w/w) fermentable sugar
Production capacity/day	30 m^3
Molasses consumption/day	117–121 tonnes
Process outlet quality	95% (v/v) rectified spirit (hydrous ethanol)
Spent wash (to be treated in effluent treatment plant)	10–12 L/L spirit (hydrous ethanol)
Steam required in distillation	2–2.5 kg steam per litre of ethanol
Cooling water required	84 m^3
Electric power consumption	About 180 kW

The alcohol concentration during the fermentation remains until 7–9% (v/v). In the distillation column, continuous distillation of the lean aqueous solution is performed to get 95% (v/v) concentrated rectified spirit alcohol. The distillation process consumes a larger part of the electrical power and process heat than the fermentation process.

Power consumption to run the pumps, blowers and other ancillaries installed in this unit is 180 kW. The installed production capacity of the plant is 30 m^3. It is found that 117–121 tonnes of molasses (42%, w/w) are required as input to run the plant in full capacity. To optimize production, extra molasses could be purchased from other sugar mills to run the plant throughout the year as only 100.3 tonnes are readily available at the plant. Table 6 provides detail figures about the plant.

Presently, rectified spirit is being produced and sold to medical applications and alcohol industries. 2.25 kg of steam (average value) is required to produce 1 L of rectified spirit. With the available molasses (100.3 tonnes/day) inside the factory, 24.86 KL of rectified spirit can be produced. The total primary energy requirement is 314 GJ/day (power: 73.7 GJ and heat: 240.3 GJ). Here, power is calculated based on the share of 180 kW electricity as mentioned in cogeneration section 2.3.2 above (3000 kW is equivalent to 1229.4 GJ/day).

2.3.5. Dehydration process

SRSM has installed capacity to produce 30 m^3 anhydrous ethanol (99.5% bioethanol) to sell to Nepal Oil Corporation (NOC) for blending purposes, and this is the only ethanol plant aimed at bioethanol fuel production in Nepal. In spite of Nepal government's decision to blend 10% (v/v) bioethanol in transport fuel–gasoline in 2004, SRSM could not sell to NOC due to conflicting purchasing policy. According to government purchasing policy, there should be at least three bidders to compete for the purchasing process. As a result, the plant is not operational at the moment.

In this plant, water content of hydrous ethanol is further removed to recover anhydrous ethanol (EtOH, 99.5%) in the distillation column. According to SRSM, 0.5–0.6 kg of steam is required to produce 1 L of anhydrous ethanol, and power consumption is estimated to be 0.2 kWh/L [22]. Process losses of ethanol add up to 3–5%.

Thus, 0.55 kg of steam (average value) is required to produce 1 L of anhydrous ethanol (EtOH) and power consumption is estimated to be 190.5 kW. It is calculated that total primary energy needed in this stage would be 132.1 GJ (power: 78.1 GJ and steam: 54 GJ) to produce 22.87 KL EtOH per day.

2.3.6. Effluent treatment plant (ETP)

SRSM is also equipped with an effluent treatment plant (capacity: 360 m^3/day; 1 KL = 1 m^3) to treat distillery waste water, called spent wash, so as to reduce the environmental load of the plant. To produce 1 L of ethanol, 12 L of waste water (spent wash) is generated. Hence 30 m^3 ethanol generates 360 m^3 of effluent per day. The effluent contains high biological oxygen demand (BOD) and chemical oxygen demand (COD) values. Table 7 shows BOD and COD, including other characteristics of waste water coming out from the distillery.

Table 7
Effluent characteristics of distillery waste water (spent wash).

Properties	Values
COD (chemical oxygen demand)	110,000 mg/L
BOD (biological oxygen demand)	55,000 mg/L
pH	3.5–4.5
TSS (total suspended solid)	5000 mg/L
TS (total solid)	11–12% (w/w)
Temperature	75 °C

The primary treatment process is anaerobic in nature. COD load is reduced in a range of 22,000–28,000 mg/L and 70% reduction occurs in BOD from its initial value, pH value increases to 7–7.2. It is found that 0.53 N m^3 of biogas (68% methane, heating value 5500–5800 kcal/N m^3) is produced per kg of COD reduction [23].

300 m^3 of the spent wash (generated by 25 KL rectified spirit in one day) is treated in the biological effluent treatment plant. COD (chemical oxygen demand) is reduced from 110,000 mg/L to 25,000 mg/L (average value). Taking an average heating value (5650 kcal = 23.65 MJ/N m^3) of biogas, it is found that 0.54 N m^3 of biogas is produced per kg of COD reduction. In 1 L of spent wash, there is a reduction of 85,000 mg of COD, which gives 45 L (0.045 m^3) of biogas. This biogas is utilized in the boilers to save bagasse. Primary energy gains come out to be 319.3 GJ. Electrical power required for the plant is found to be around 80 kW to drive motors and pumps, and assigned primary energy per day is 32.8 GJ.

3. Material and energy balance estimation

3.1. Sugarcane product chain

The SRSM plant was running at about 67% plant utilization factor (installed capacity is 3000 tonnes cane/day) at the time of visit to the sugar mill. 2010 tonnes/day of sugarcane crushing data was used, which produces 181.90 tonnes of sugar and 100.30 tonnes of molasses. Again, 121 tonnes molasses (42%, w/w) is required to produce 30 m^3 (full capacity) of rectified spirit (95% (v/v) ethanol). Further, 30 m^3 rectified spirit yields 27.6 m^3 of final ethanol (EtOH, 99.5% (v/v) assuming process loss is 3%). Thus, while processing 1020 tonnes of sugarcane – 100.30 tonnes of molasses produce 22.87 m^3 of EtOH in one day, generating intermediate rectified spirit 24.86 m^3. To produce 1 L of ethanol, 12 L waste water (spent wash) is generated. While treating this amount of waste water in the anaerobic digester, 0.54 N m^3 biogas is produced. In brief, to produce 1 L of final ethanol (EtOH), the product chain depicted in Fig. 4 applies. Observe that the numbers in tonnes refer to 1-day production of the respective products.

3.2. Energy balance estimation

3.2.1. In the sugarcane farming

Primary energy consumption in 1 ha of sugarcane farming to produce 40.61 tonnes of sugarcane is 45,371.6 MJ (see Table 8). The share of fossil energy inputs and renewable energy inputs are 67.5% and 32.5% respectively. Out of fossil fuel inputs, diesel used for the irrigation contributes 43.2%. Fertilizers/chemicals carry 45.7%. Since the transportation is mainly done by non-motorized transport, it has a small share of 5.9% in total fossil fuel input. As mentioned earlier, fossil and renewable energy inputs for human labour are divided as per their contribution in the national primary

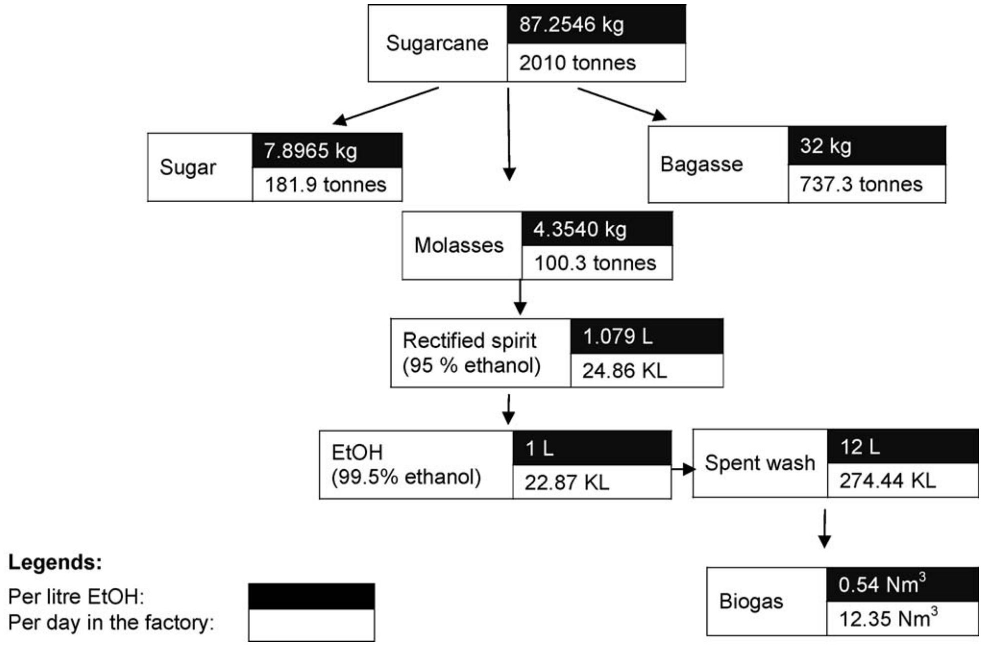

Fig. 4. Sugarcane product chain in the SRSM factory.

energy consumption, whereby labour energy input is dominated by renewable energy.

3.2.2. In the factory operation

The sugar factory generates 737.3 tonnes of bagasse per day, which have 7036.5 GJ heating value. The sum of the primary energy requirements in the different processes of the plant gives total energy demand of 7355.8 GJ/day. Bagasse and biogas account for the plant's energy supply. Table 9 shows the primary energy balance considering all processes. It is found that there is a surplus of 17% of the bagasse generated, equivalent to 129.1 tonnes/day. Sugar milling process consumes a large amount of primary energy (73%), and fermentation/distillation and dehydration only take 4% and 2% respectively (see Fig. 5). The calculation is made on 2010 tonnes sugarcane processing per day and 36.68% bagasse content in the sugarcane.

4. Results and discussion

To evaluate primary energy consumption for the production of 1 L anhydrous ethanol (99.5% EtOH, MOE) according to the process route showed in Fig. 4, the product chain of sugarcane, molasses (and sugar), rectified spirit and MOE is analyzed. Until the process point where sugar and molasses are attained, the primary energy is shared between the two products, sugar and molasses, in the ratio of 22.2:1 as mentioned in Section 2.3.3 above.

An estimation of the life cycle energy inputs throughout the process is shown in Table 10. It is observed that the renewable energy contribution amounts to 91.7% to produce 1 L of MOE since most of the operations are run with the use of bagasse, biogas and non-motorized transportation except in the application of fertilizers/chemicals and irrigation. Fermentation/distillation is the most energy intensive part of the process, consuming 12.6 MJ/L, followed by sugar milling which consumes 10.5 MJ/L. Fig. 6 visualizes the energy requirements of each stage.

Table 8
Primary energy requirement in one hectare sugarcane farming (40.61 tonne/ha).

Activity	Fossil energy inputs (MJ/ha)	Renewable energy inputs (MJ/ha)
1. Sugarcane farming		
Fertilizers		
Phosphorous (P_2O_5)	382.1	–
Potash (K_2O)	387.8	–
Nitrogen	7883.7	–
Pesticides/insecticides	4761.4	–
Herbicides	586.7	–
Diesel (irrigation)	13,227.7	–
Human labour	1625	14,723.5
2. Diesel (transportation)	1793.6	–
Sub-total (fossil and renewables)	30,648.1	14,723.5
Total	45,371.6	

Table 9
Primary energy balance in the sugar milling (including distillation, dehydration and ETP).

Processes	Sectors	GJ/day
Primary energy required		
Sugarcane milling	Power (including electricity to facilities)	990.3
	Heat	4600
Fermentation/distillation	Power	73.8
	Heat	240.2
Dehydration	Power	78.1
	Heat	54
Effluent treatment plant (ETP)	Power	32.8
Lighting in the distillation, dehydration, ETP plus electricity in their facilities	Power	54.5
Total primary energy required		6123.7
Primary energy supply		
Bagasse primary energy input		7036.5
ETP biogas input		319.3
Total primary energy input		7355.8
Excess bagasse		1232.1
% excess bagasse		16.75%

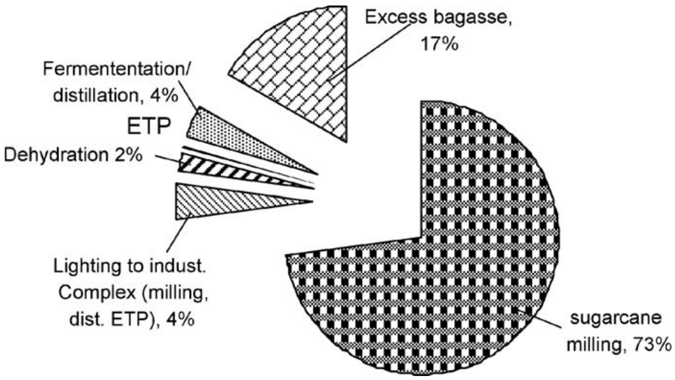

Fig. 5. Utilization of the available primary energy (bagasse: 96% and biogas: 4%).

Considering the energy content of anhydrous ethanol (MOE) aimed as transport fuel, the value of 21.2 MJ/L (lower heating value) attained shows that the net renewable energy value (NREV) is positive (18.36 MJ/L) but the NEV is negative (−13.05). The excess bagasse, which is wasted, is taken into account in the calculation. The negative value of NEV shows that more energy is required to make MOE than its final energy content. More interesting in this case is to notice the high positive value of NREV which indicates that the amount of fossil fuels used in the production cycle of the ethanol is quite low. The ratio between energy content of the ethanol fuel to fossil fuel inputs is 7.47.

Different studies have estimated the life cycle energy balance of ethanol derived from various feedstocks such as sugarcane, cassava, corn, cane-molasses. Macedo et al. found that the fossil energy required to produce 1 tonne of cane was 210 MJ and fossil inputs to ethanol energy content ratio (energy yield ratio) in the production phase of sugarcane ethanol was 9.3 in Brazil during 2005/2006, considering direct consumption of external fuels and electricity, energy required for the production of chemicals and materials, and additional energy necessary for the manufacture, construction and maintenance of equipment and buildings [11]. Positive NEV and net renewable value (NREV) of cassava based ethanol were reported by Nguyen et al. in Thailand, considering life cycle materials, fuels and human labour inputs [6]. The values of NEV and NREV were 8.8 MJ/L and 9.15 MJ/L respectively. Similarly, the results of NEV and NREV for cassava fuel ethanol as reported by Dai et al. in the case of China were 7.47 MJ/L and 7.88 MJ/L respectively [8]. Shapouri et al. reported that the net energy balance (energy yield ratio) for producing corn ethanol in USA was 1.67 [9]. Nguyen et al. analysis on life cycle analysis of molasses ethanol estimated the values of NEV, NREV and energy yield ratio (for both per MJ petroleum and fossil inputs) in a Thai case, finding −5.67 MJ/L, 5.95 MJ/L and 6.12 (per MJ oil inputs) respectively [7]. Blottnitz et al. conducted a review on bioethanol fuel from life cycle perspective, comparing energy yield ratios (ratio of energy output of the biofuel to the fossil energy input) despite differing assumptions and system boundaries [24]. Thus values of energy yield ratio differ significantly due to feedstock used and production practices applied. It is, therefore, difficult to compare the net energy values (NEV and NREV) and energy yield ratios of ethanol production without clearly defining the methodological approach, system boundaries, allocation methods, and specific feedstock characteristics [25].

Table 10
Life cycle energy balance of molasses based ethanol (MOE) fuel.

Activity	Fossil energy inputs (MJ/L EtOH)	Renewable energy inputs (MJ/L EtOH)
Sugarcane farming	2.838	1.364
Fertilizers		
Phosphorous (P_2O_5)	0.035	–
Potash (K_2O)	0.036	–
Nitrogen	0.730	–
Pesticides/insecticides	0.441	–
Herbicides	0.054	–
Diesel (irrigation)	1.225	–
Human labour	0.150	1.364
Diesel (transportation)	0.166	–
Sugarcane milling (including power to facilities)	–	10.460
Fermentation/distillation	–	12.631
Dehydration	–	5.776
Effluent treatment (power)	–	1.311
Lighting in the all ethanol processes, ETP and their facilities		2.180
Excess bagasse		−2.305
Sum	2.838	31.417
Energy content of EtOH (LHV)	21.200	
Net energy value (NEV)	−13.055	
Net renewable energy value (NREV)	18.362	
Energy yield ratio	7.47	

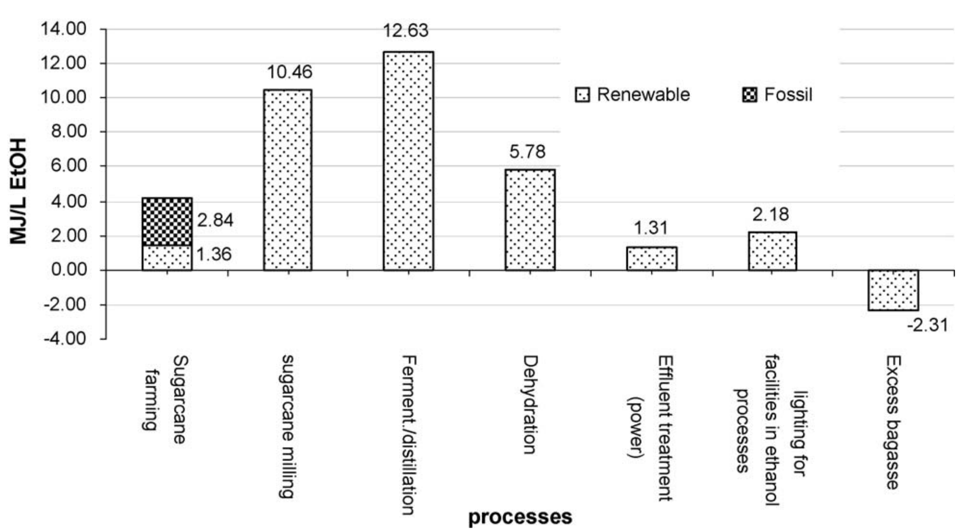

Fig. 6. Fossil and renewable energy contribution to produce 1 L of EtOH (MOE) in Nepal.

A case similar to Nepal's molasses ethanol was performed by Nyugen et al. in Thailand [7]. Energy inputs in sugarcane farming were diesel fuel (farming and transportation), fertilizers/herbicides and human labour. NEV (−5.67 MJ/L) and NREV (5.95 MJ/L) in the Thai case contrast with the values of −13.05 MJ/L and 18.36 MJ/L found in the Nepalese case. However, in the Thai case, the plant's energy requirements are not met by bagasse and biogas only. Rice husks and wood waste are used as supplementary fuels in sugar milling, and coal is a major fuel in the ethanol conversion process. On the other hand, excess electricity is sold to the grid as energy outputs. Biogas is not utilized for process energy. The difference in the value of NEV is justified by higher total energy inputs (both fossil plus renewable) in the case of Nepal, while favorable conditions for NREV prevails in Nepal since energy requirements are mostly met by renewables. Lower energy allocation value for molasses also plays an important role to improve NREV in Nepal. In any case, energy yield ratio is more encouraging for Nepal's case.

The above comparison illustrates the difficulties to make comparisons even in nearby regions due to the varying conditions in terms of how the production chain is organized and energy inputs and outputs are incorporated along the full chain. In addition, local market conditions affect the results of NEV and NREV. The price of molasses plays an important role in the net energy values and energy yield ratio found for Nepal. The 22.2:1 ratio is used for the energy inputs partition between sugar and molasses based on their current prices. However, the price of molasses has been traditionally quite low in Nepal (about $29/tonne in 2006 and $36/tonne in 2007). These low prices contrast with international prices of molasses reported by Gonsalves, at the level of $50/tonne in 2004 and $100/tonne in 2006 [26]. As the demand for ethanol increases, we can expect molasses price to rise. NEV, NREV and the energy yield ratio decrease with the increase in molasses price. For example, a 100% increase in the price of molasses leads to a reduction of 90.2% in the net energy value and 14.7% in the net renewable energy value. Higher values support the worthiness of the fuel. The energy yield ratio gets reduced by 48.8%, giving a figure of 3.88, whose higher value also provides the merit of the fuel. If an increase of 50% in molasses prices is considered, there shall be a reduction in NEV and NREV by 47% and 7.7% respectively getting the energy yield ratio 4.99.

As can be gathered from the process description and calculations, there is a significant potential to improve the energy balance of the ethanol production in Nepal. One important way to achieve this is to save energy (power and process heat) in the plant. With 10% reduction in energy consumption in the plant, NEV increases 33.5%. The break-even point when NEV reaches zero occurs at 30% reduction in energy consumption. Although this is possible from a technological point of view, it is difficult to achieve that point at the current technological settings in the plant.

5. Conclusion

The main energy source required to produce MOE in Nepal is bagasse, which is renewable and a by-product of sugarcane. Biogas generated in effluent treatment process is also one of the energy sources used in the process. Fossil fuel consumption to produce 1 L of MOE is 2.84 MJ, giving a good energy yield ratio (7.47) and NREV (18.36 MJ/L). The higher value of NREV indicates the low amount of fossil fuels used in the production cycle of ethanol in Nepal. However, the total energy requirement (fossil plus renewable) is 34.26 MJ/L, which is higher than the energy content in 1 L of MOE, giving a negative NEV (−13.05 MJ/L). This is due to various inefficiencies along the production chain.

It is observed that the renewable energy contribution amounts to 91.7% to produce 1 L of MOE since most of the operations are done by bagasse, biogas and non-motorized transportation except in the application of fertilizers/chemicals and irrigation. Energy consumption in the fermentation/distillation process is the highest (12.63 MJ/L), while sugar milling consumes 10.46 MJ/L, taking the second place.

It is noticed that the variation in the price of molasses has a significant effect on the net energy values and the energy yield ratio. When the price of molasses rises by two-fold of the current price, the energy yield ratio is reduced to 3.88 (48.8% reduction). NEV and NREV also decreased by 90.2% and 14.7% respectively. In this case, the total energy input (fossil plus renewables) required rises to 46 MJ to produce 1 L of MOE.

Assuming the potential of energy saving in sugar milling and ethanol conversion, it is found that 10% reduction in energy consumption helps to increase 33.5% in NEV. The values of NREV and energy yield ratio remain constant since there are no fossil fuel inputs in the production processes inside the factory. An improvement of 30% in the efficiency of the plant will result in a break-even point for NEV, that is, a point where the energy input in the system and the output in terms of energy content in the ethanol is equal.

In any case, NREV and the energy yield ratio are strong reasons to give preference for the ethanol as transport fuel in a country that does not have its own oil and where oil imports imply a tremendous burden on the national economy. The renewable energy inputs in the ethanol production are found within the country and result in job generation and income. Energy savings in the factory operation could be instrumental in increasing the merit of MOE. Further energy and socio-economic gains can be achieved through improvement on the agricultural side since cane yields are still very low in Nepal.

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